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The Office of Nuclear Smuggling Detection and Deterrence

Poland Peer-Peer Engagement: Radiation Detection System Components

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Overview

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I. **Materials of Interest and Minimum Detectable Quantity**
II. **Factors in Neutron and Gamma Detection**
III. **Alarm Handling Differences**
IV. **Gamma Alarm Algorithm-TSA/Rapiscan**
V. **Neutron Alarm Algorithm-TSA/Rapiscan**
VI. **Important Factors in Installing Portal Monitors**
VII. **Portal Monitor Parameters-calculations and importance**

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I. Materials of Interest

The potential for a terrorist group or rogue state to obtain nuclear weapons materials is considered one of the most serious threats to international security.[1]

What NSDD is looking for:

- **Special Nuclear Materials (SNM)**
  - **HEU-Highly Enriched Uranium (>20% U-235)**
  - **WGPu-Weapons Grade Plutonium (<7% Pu-240)**
    (prolific neutron emitter)
  - **U-233**
- **Weapons Indicating Materials**
  - **DU-Depleted Uranium (<0.72% U-235)**
- **Weapons Systems**

But also:

- **Other Materials Treated as SNM: Np-237, Am-241, and Am-243**
- **Radiological Dispersal Device (RDD) Materials: Cs-137, Co-60, etc.**

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I. Minimum Detectable Quantity (MDQ)

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- **Definition: the amount of material required to set off an alarm. Depends on many factors:**
  - **Local conditions**
    - **background radiation levels, lane width, etc.**
  - **Conveyance type**
    - **pedestrian, light vehicle, cargo container**
  - **Monitor settings**
    - **threshold, algorithm**
  - **Source material and form**
    - **metal, compound, isotopic composition**
  - **Desired detection probability and confidence**

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II. Minimum Detectable Quantity- Some Important Factors

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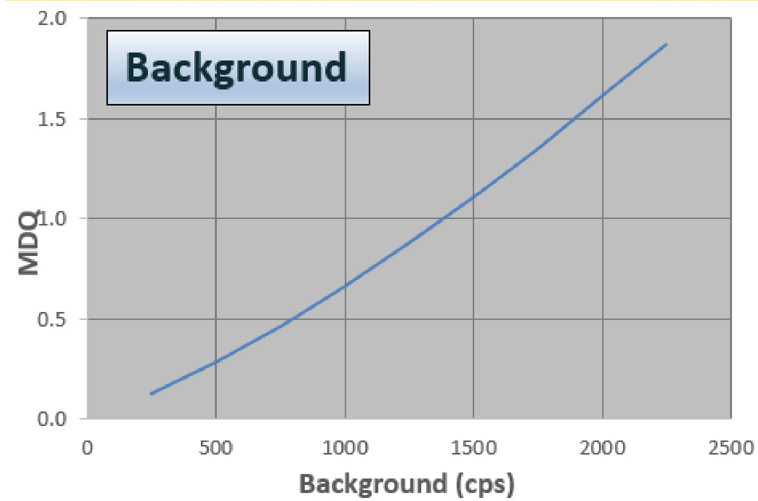
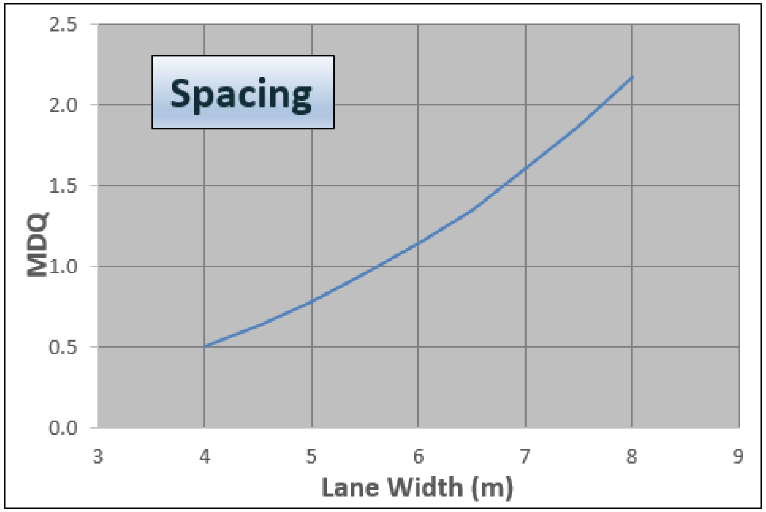
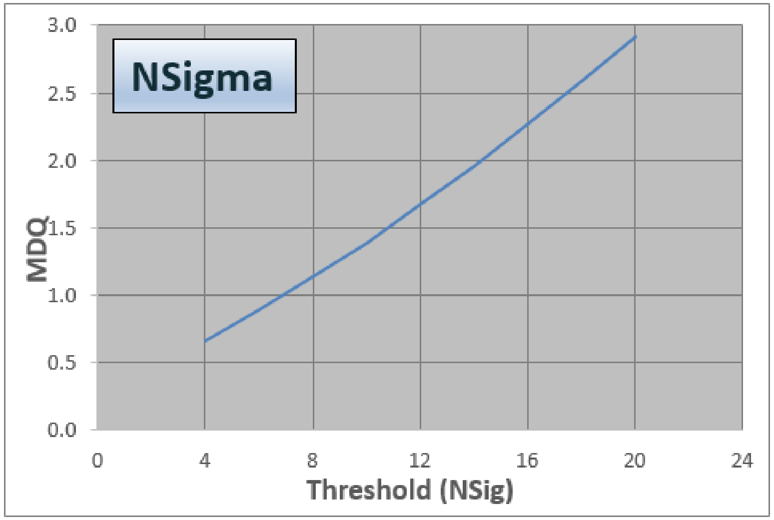
Lower is better

<u>Parameter</u>	<u>Control Mechanisms</u>
Background	repave, collimate
Speed	speed bumps, drop bar
Spacing	minimize at design phase
Alarm threshold (Nsigma)	country manager, customs
Background suppression	collimate, repave







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II. Factors in Neutron and Gamma Detection[2]

Threat sources may be small (compact) inducing low count rates

- Self-shielding (metals block their own gamma emissions well, U, Pu)
- Low gamma emission rates (HEU, DU)
- Low energy gammas easily shielded (HEU)

Threat sources may be externally shielded providing low count rates

- Shielded by cargo
- Shielded by design
- Background suppression

If we release low-sigma alarms, we may be releasing a threat source

- Quite large sources can be hidden from detection due to a combination of the above factors

III. Primary Inspection Problem Statement[3]

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- **The number of occupancies that occur each year in the Nuclear Smuggling Detection and Deterrence (NSDD) program[4] is large: ~100 million for the entire deployed fleet**
- **This leads to a very large number of gamma alarms and a considerable number of neutron alarms, each of which should be addressed**
  - **Gamma alarm rates: ~1 in 100**
  - **Neutron alarm rates: ~1 in 10,000**
- **Given resource limitations, what can be done to reduce these numbers to manageable levels without losing sight of detection goals, and**
- **Can any of these alarms be adjudicated based on primary screening monitor data alone? Short answer: gamma-no, neutron-yes.**

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III. Alarms in Primary Inspection-Causes[3]

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- **Gamma Alarms**
  - **Naturally occurring radioactive material (NORM):** vast majority of all alarms
  - **Non-Intrusive Interrogation (NII) Interference:** not infrequent and often problematic
  - **Noise induced (internal relay, keypad, percussion, radio frequency):** infrequent occurrence but all have been observed
  - **Radon washout:** frequent occurrence but self-remedying (wait ~hours)
- **Neutron Alarms**
  - **Cosmic ray-induced**
  - **Noise induced (PMFX pickoff box, connectors)**
  - **Percussively-induced, keyboard-induced alarms**
  - **Statistical false alarms-short background evaluation time**
  - **Real neutron sources (Pu, Cf-252, AmBe, PoBe, etc.)**

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III. Reducing Sensitivity to NORM[3]

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- Energy window has been chosen to enhanced SNM detection
- Reduces sensitivity to NORM and DU
- Collimation applied to reduce background
  - No collimation, acceptance angle is wide: 78° FWHM*
  - With collimation, it is about 42° FWHM
  - Reduces background radiation from surroundings
  - Reduces signature from extremes of extended NORM loads
- Redesign of collimator could improve results with minimal loss in detection sensitivity

*Full width at half maximum

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III. Reducing Sensitivity to NORM[5]

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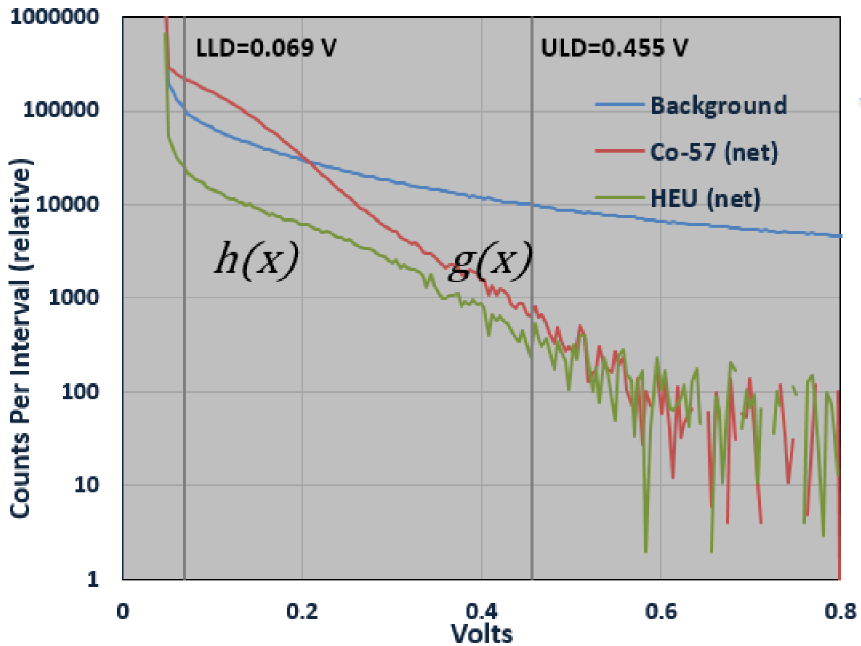
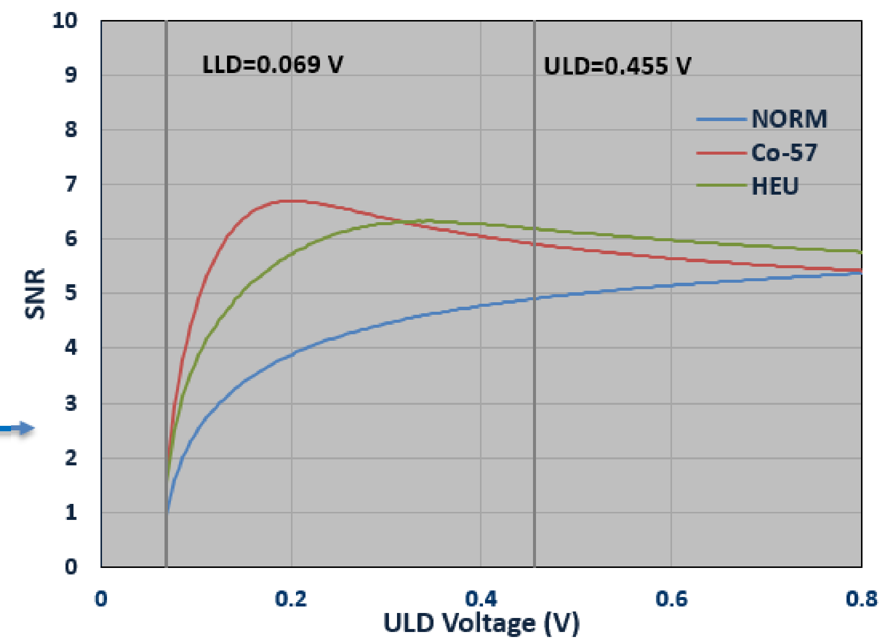


Spectra in PVT Detector (polyvinyl toluene)



Signal-to-Noise Ratio (SNR) vs Upper Level Discriminator (ULD)

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III. Reducing Sensitivity to NORM-Collimators[5]

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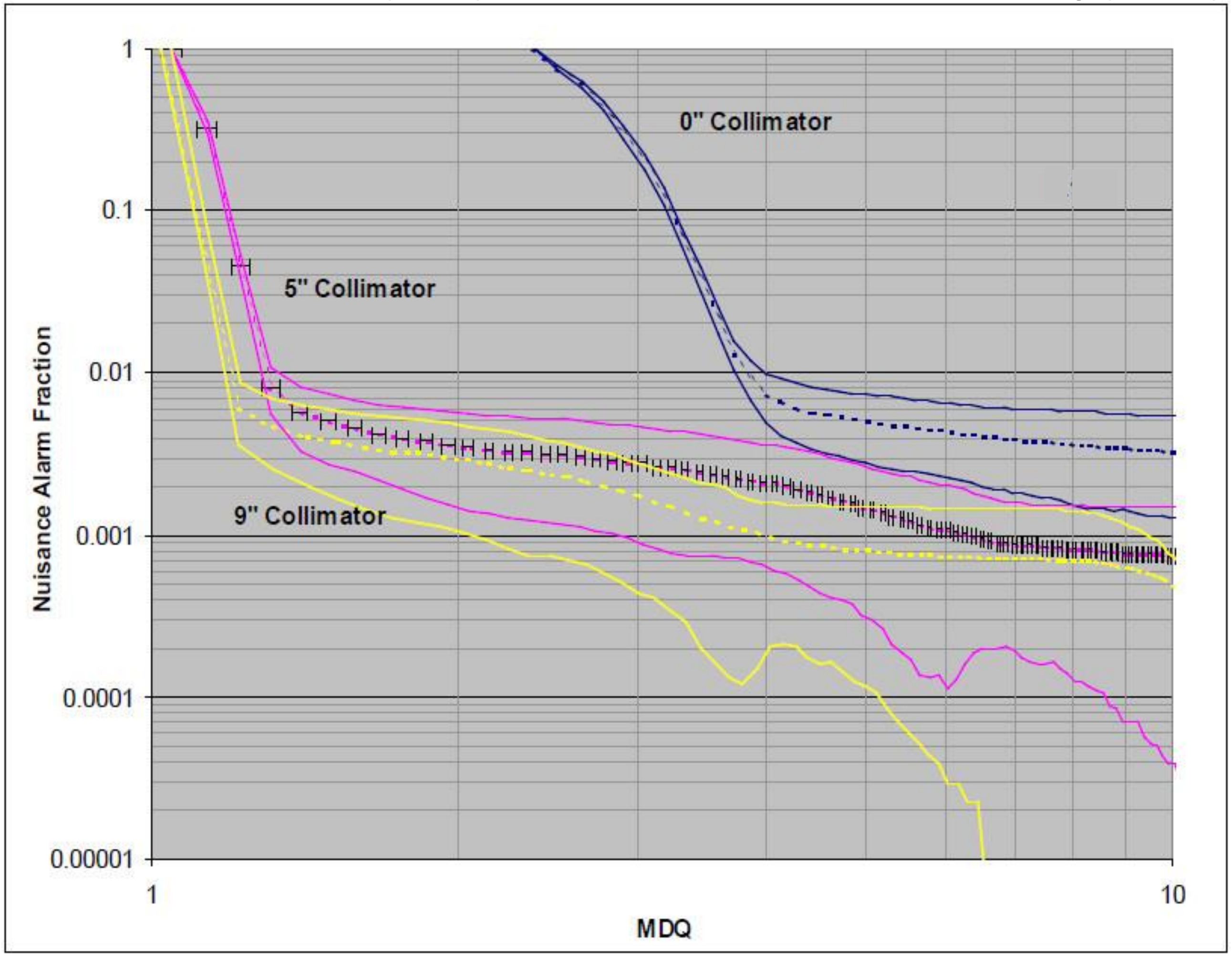
Nuisance Alarm Rate (NAR) vs Minimum Detectable Quantity (MDQ)



- **Collimation reduces sensitivity to NORM and lowers background**
- **For any chosen NAR, MDQ is lower with increased collimation**
- **For any chosen MDQ, NAR is lower with increased collimation**
- **Note: 9" extends beyond standard cabinet forcing wider lane width; omitted here (yellow curve would shift right).**
- **NAR = NORM-induced + background-induced**

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III. Alarm Handling-Neutron or Neutron/Gamma

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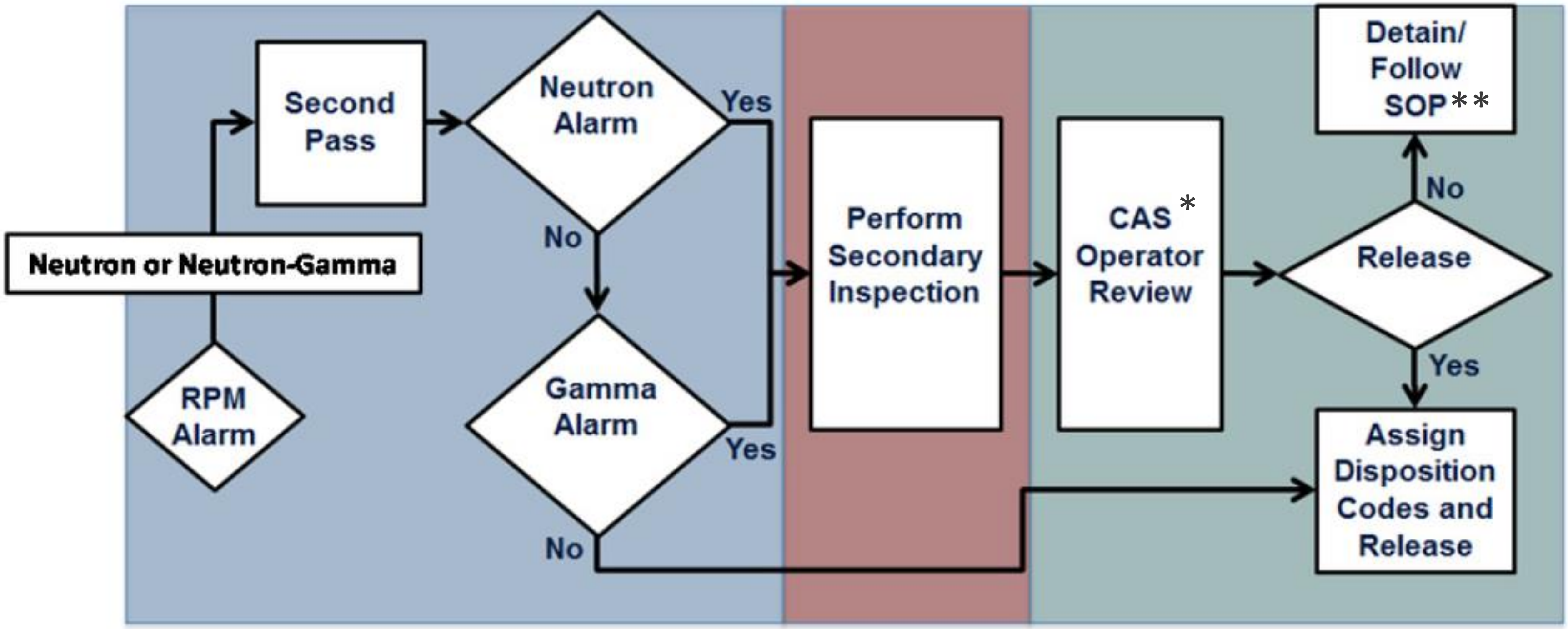

[6]

1. If a neutron alarm occurs, send container through a <u>different</u> monitor for a second pass.
2. If a neutron alarm occurs again, it is <u>highly likely</u> a neutron source exists.
3. If no neutron alarm on second pass, it is <u>highly unlikely</u> there is a neutron source.

*Central alarm station
**Standard operating procedure

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III. Alarm Handling-Gamma

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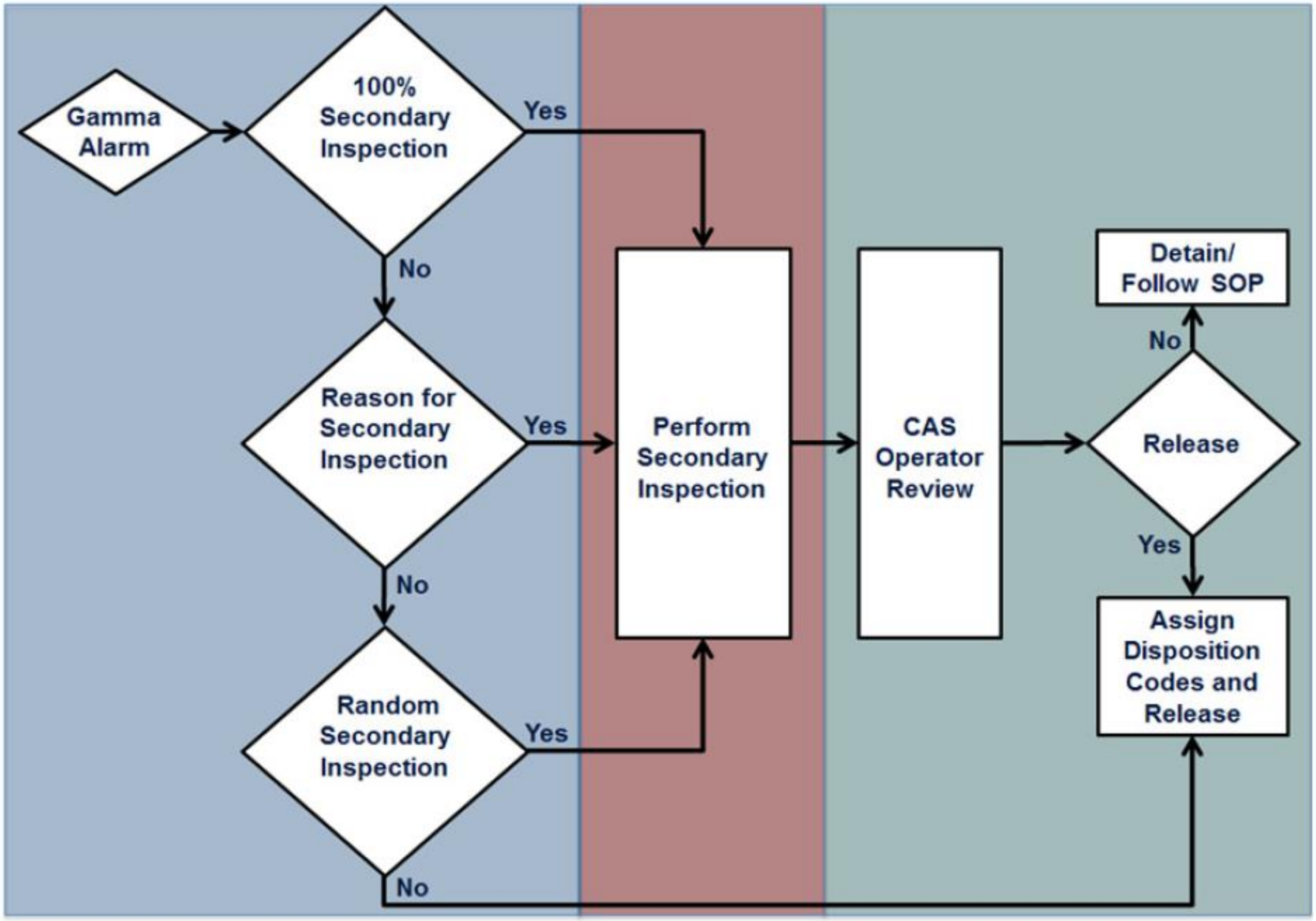

[6]

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IV. Gamma Alarm Algorithm[5]

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Terminology

- Occupied: ultrasonic or infrared (break beam) sensor has been triggered, starts measurement of vehicle or pedestrian
- Unoccupied: sensor is unbroken, background is updated

Process

- Background measurement: 20 s in duration and updated in 5-s pieces when unoccupied (reported every 5 s)
- During occupancy, gamma measurement data is reported every 200 ms
- Every 200 ms, the rolling **1-second gamma count rate (S)** is compared to the **background 1-second count rate (B)**
- If the **signal-to-noise ratio, SNR = (S-B)/√B)** exceeds the preset **threshold (N, Nsigma),** an alarm is triggered

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IV. Gamma Alarm Example[5]

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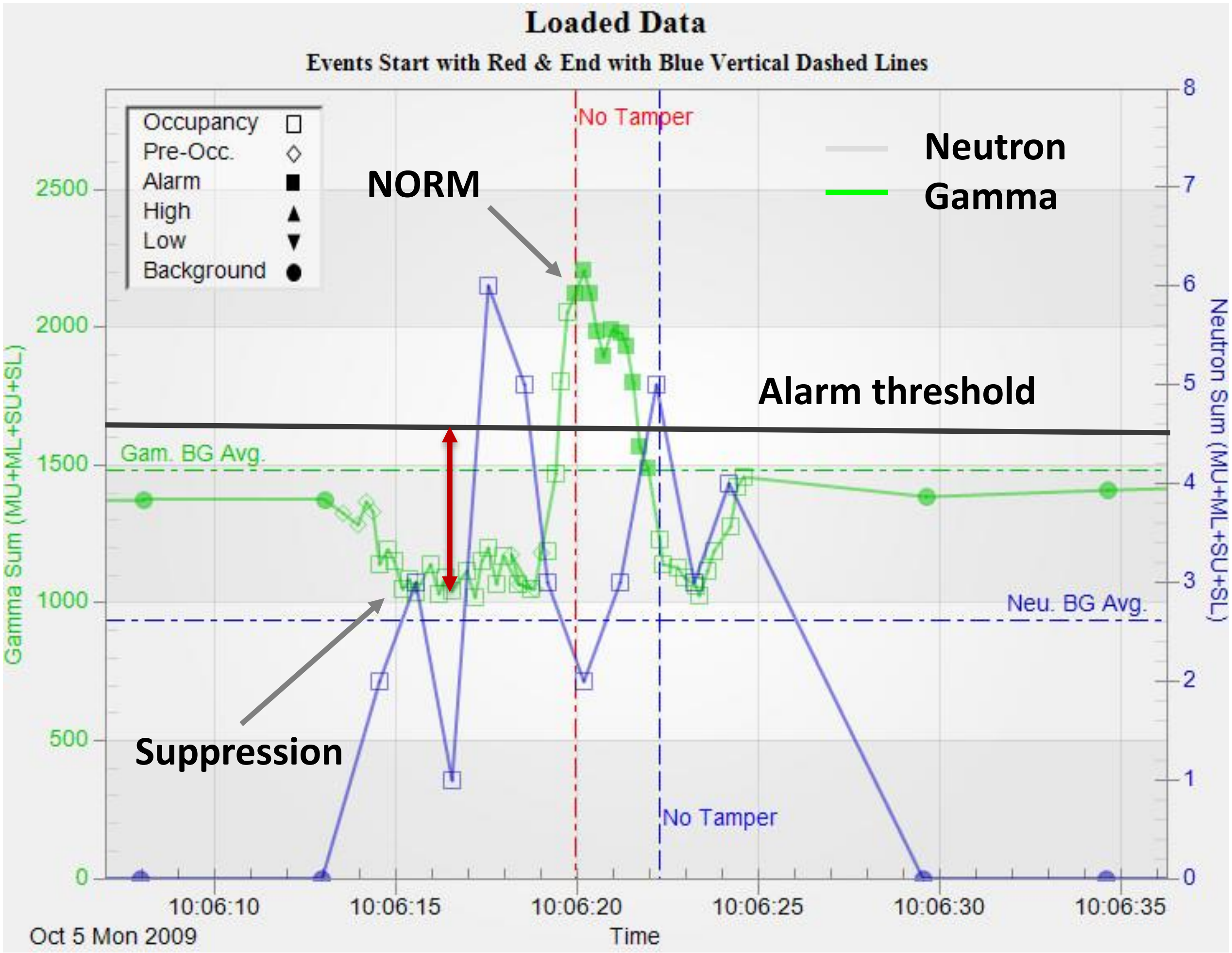

Threshold (Nσ): N = 7.0
Background: B = 1380 cps
Src+bkg rate: S = 2200 cps

$\sigma = \sqrt{B} = 37$ cps

SNR = (S-B)/ σ = 22

In this case:

SNR > N σ -> alarm

Load activity was sufficiently large to exceed suppression well and surpass the alarm threshold

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IV. Background Suppression Example[5]

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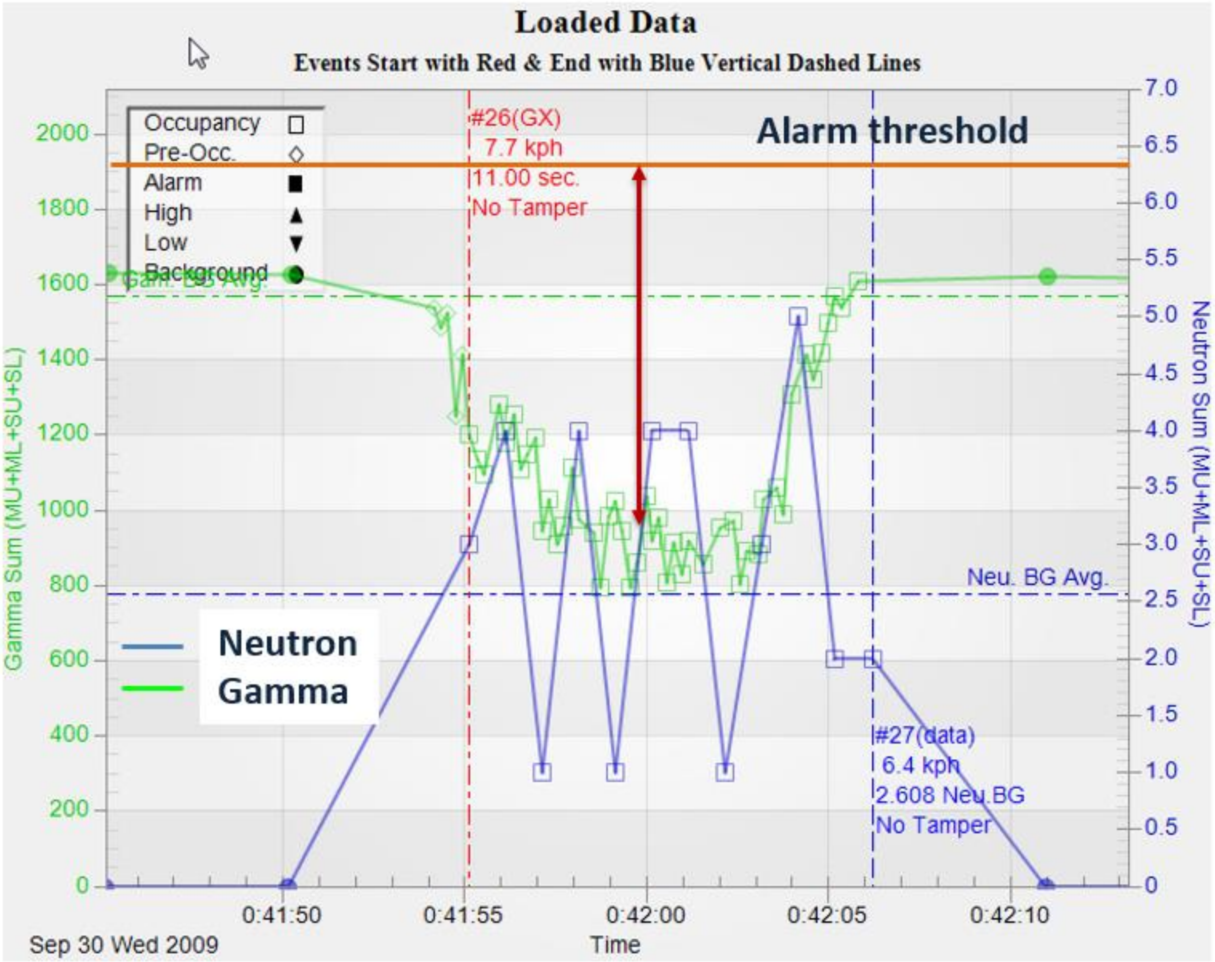

Threshold (Nσ): **N = 7.0**
Background: **B = 1630 cps**
Src+bkg rate: **S = 950 cps**

$\sigma = \sqrt{B} = 40$ cps

SNR = (S-B)/ σ = -17

In this case:

SNR < N σ -> no alarm

Load activity insufficient to exceed the alarm threshold

Suppression greatly reduces sensitivity

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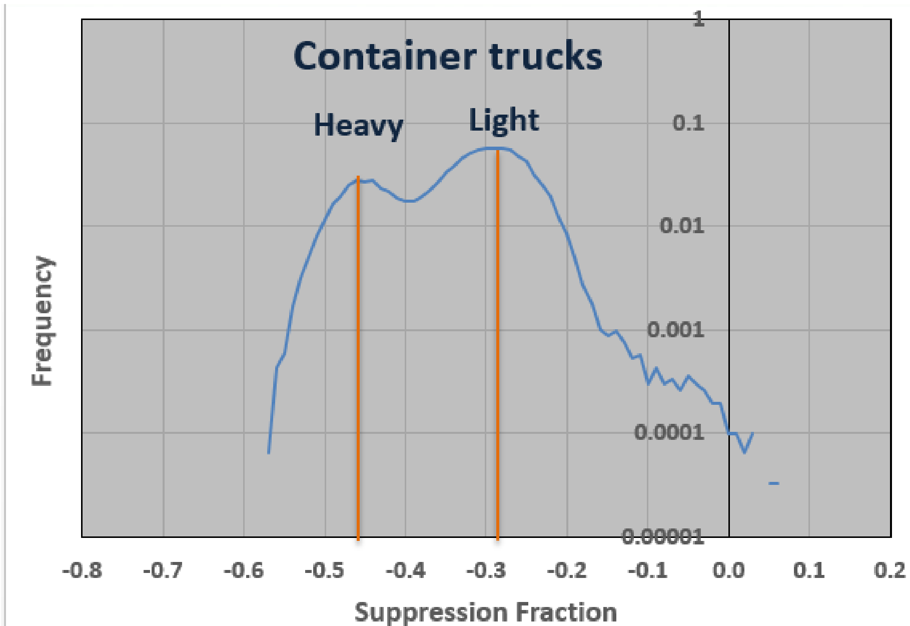
IV. Background Suppression Distribution[5]

Container trucks

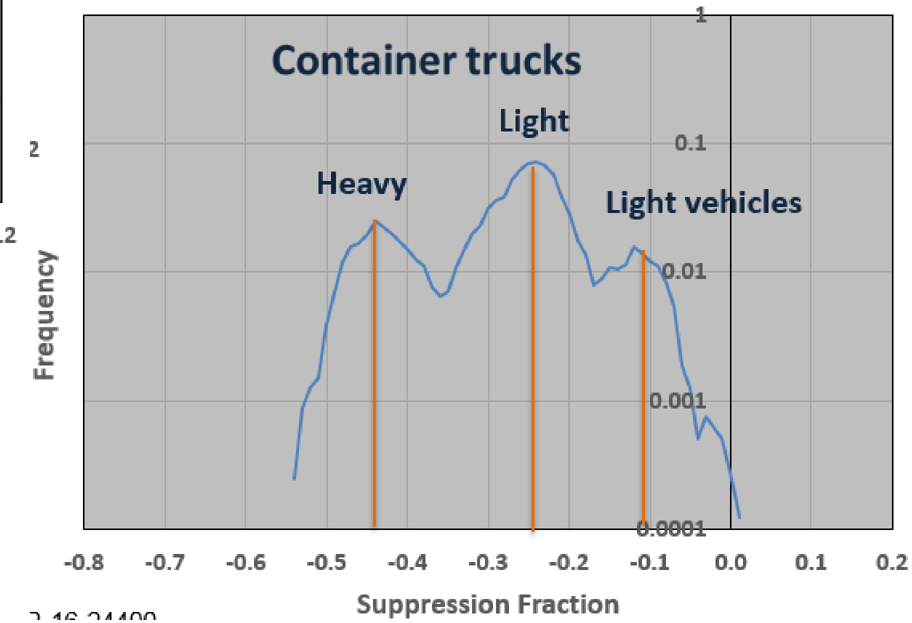


Empty container & trailer: 20-25% supp.

Collimation helps mitigate the negative effects of background suppression by reducing background levels (suppression as a fraction little changed)

Stream of commerce suppression distribution varies lane to lane and with time

Appears to have three modes consistent with: light vehicles, empty or lightly loaded containers, and heavily loaded containers



V. Neutron Detection Algorithm-Truncated SPRT

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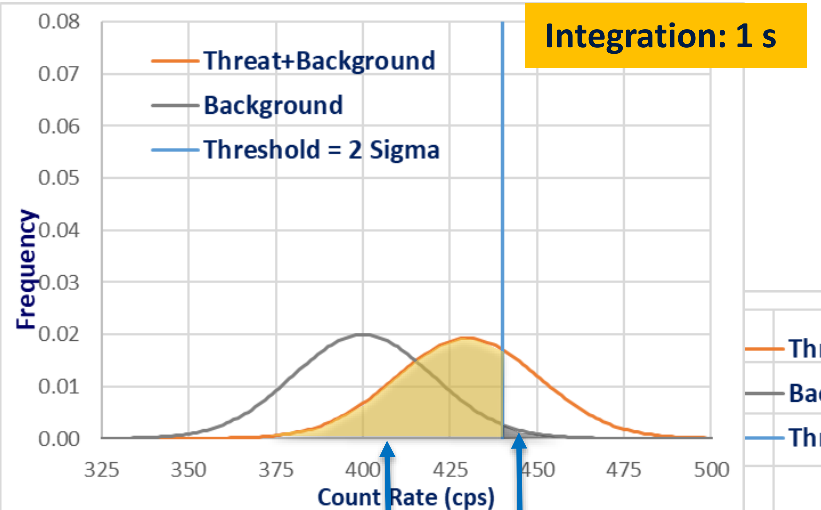
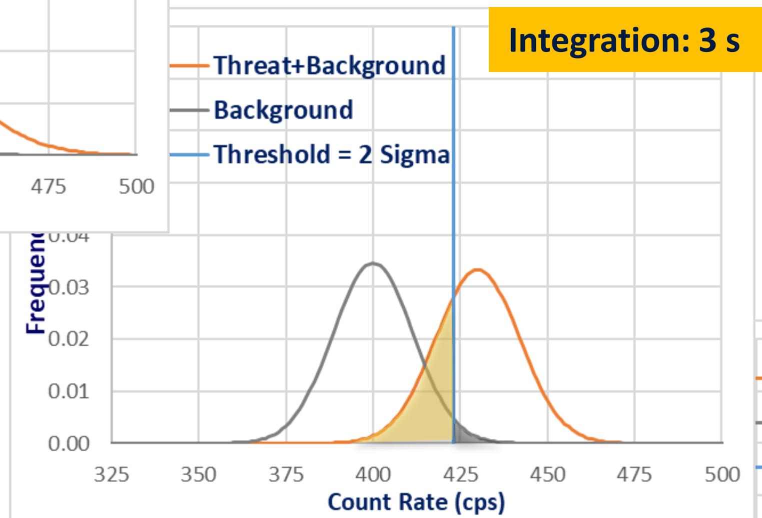
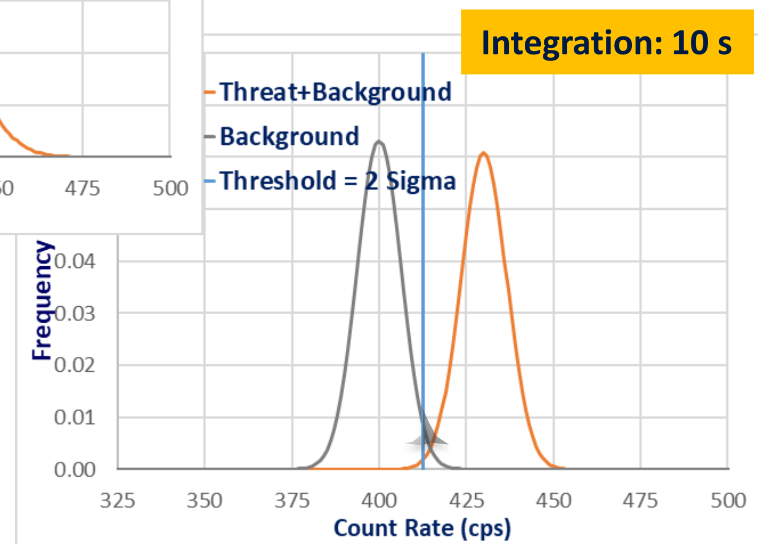
Integrates signature until specified false positive and false negative rates are met



False negative

False positive





V. Neutron Detection Algorithm- Truncated SPRT[5]

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Sequential Probability Ratio Test (SPRT) is a hypothesis test in which the sample size is not determined in advance

Non-threat radiation level population mean: μ_0

Threat radiation level population mean: μ_1

Null hypothesis (H_0): radiation levels consistent with background

Alternative hypothesis (H_1): radiation levels consistent with threat

Type I error (α): **Choose H_1 when H_0 is true (false positive)**

Type II error (β): **Choose H_0 when H_1 is true (false negative)**

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V. Neutron Detection Algorithm-Truncated SPRT[5]

- **Radiation detection process is well-modeled by a Poisson distribution**
- **Series of measured values are used to determine whether $\mathbf{H_0}$ or $\mathbf{H_1}$ is most probable given the chosen limits for α and β**

Series of measurements: $x_1, x_2, \dots x_n$

Probability ratio: $\mathrm{f}(x_1, x_2, \dots x_n) = \dfrac{e^{-n\mu_1}\mu_1^{(x_1+x_2+\cdots+x_n)}}{e^{-n\mu_0}\mu_0^{(x_1+x_2+\cdots+x_n)}}$

Check value of f($x_1, x_2, \dots x_n$) after each measurement

V. Neutron Detection Algorithm-Truncated SPRT[5]

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Three possibilities:

1) f($x_1, x_2, \ldots x_n$) < A → H_0 (background) $\quad A = \frac{\beta}{1-\alpha}$

2) f($x_1, x_2, \ldots x_n$) > B → H_1 (threat) $\quad B = \frac{1-\beta}{\alpha}$

3) A < f($x_1, x_2, \ldots x_n$) < B → Indeterminate (take another sample)

- **The test is known to terminate though the sample size may be large depending on the parameter choices**
- **Truncation can be used to ensure the test (measurement) terminates after no more than a preset sample size**

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V. Neutron Detection Algorithm[5]

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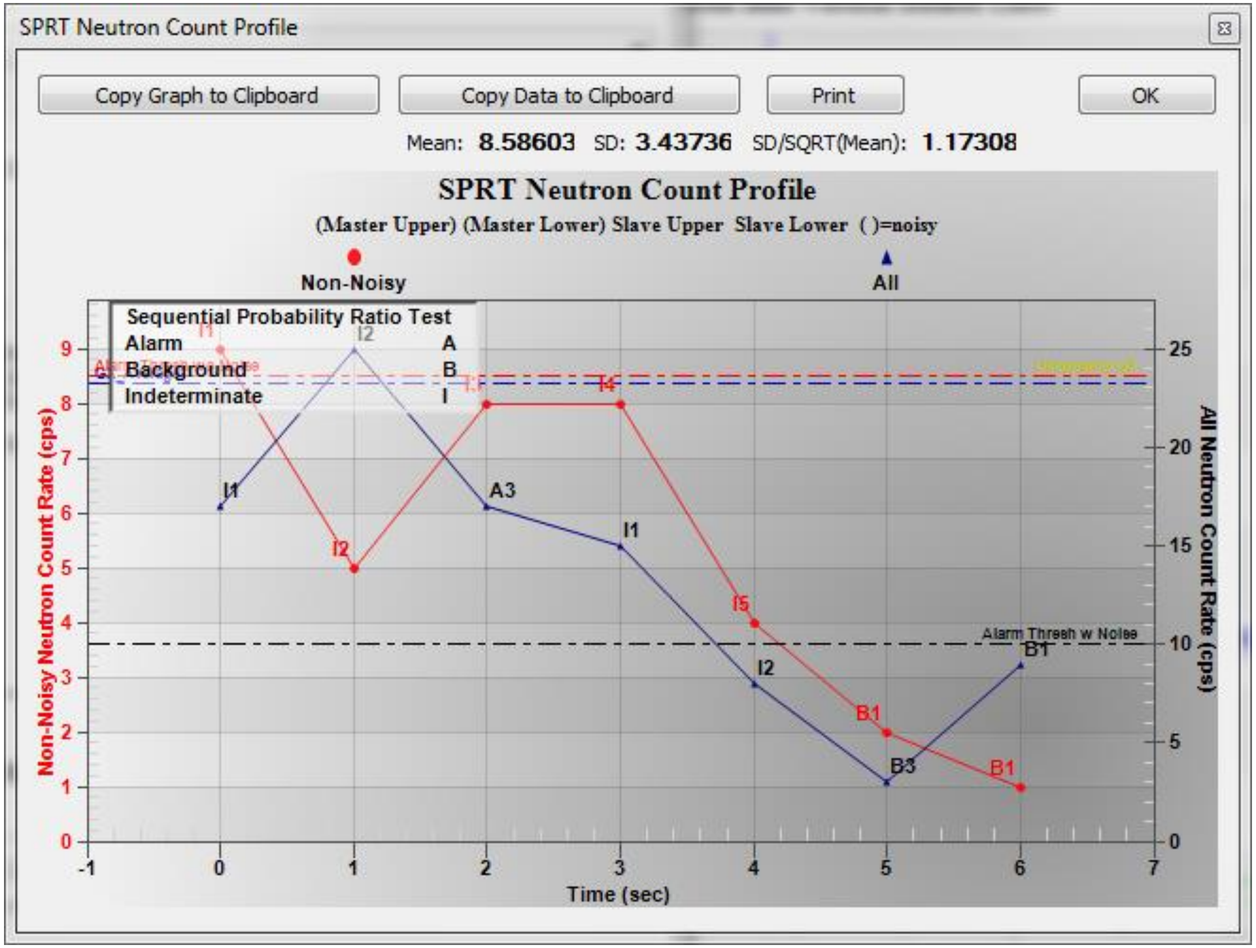

One decision per second:

- **I = indeterminate**
- **B = background**
- **A = alarm**

Look for an "A" in the replayed non-noisy data (red line)

If there is no "A", alarm is likely due to noise

Neutron alarm algorithm with all data (blue) and without noisy data (red).

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VI. Important Factors-Installing Portal Monitors

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- **Pillar spacing**: the space between the two pillars of the portal monitor; it must be wide enough for safe passage of a container on a trailer, but narrow enough to maintain a low MDQ. NSDD standard spacing is 4.6 m
- **Drive-through speed**: increasing the speed will increase (worsen) the MDQ. NSDD standard speed is 8 km/h (5 mph)
- **NSigma setting**: must be high enough to ensure adequately low FARs and nuisance alarm rates from NORM. (see OC curve)
- **Background**: the threshold for 1 false alarm in 1000 occupancies is about 4√background; therefore, the higher the background, the higher the MDQ. NSDD minimum threshold is 4 to keep FAR below 1 in 1000 occ.
- **Background suppression**: vehicle blocks background radiation when it enters a monitor. This is a very large effect that reduces sensitivity.
- NSDD specifies that instruments must meet sensitivity and FAR requirements in a background exposure rate of 20 μR/h (and therefore must be tested/evaluated in a background of 20 μR/h).

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VI. Important Factors- Installing Portal Monitors[5]

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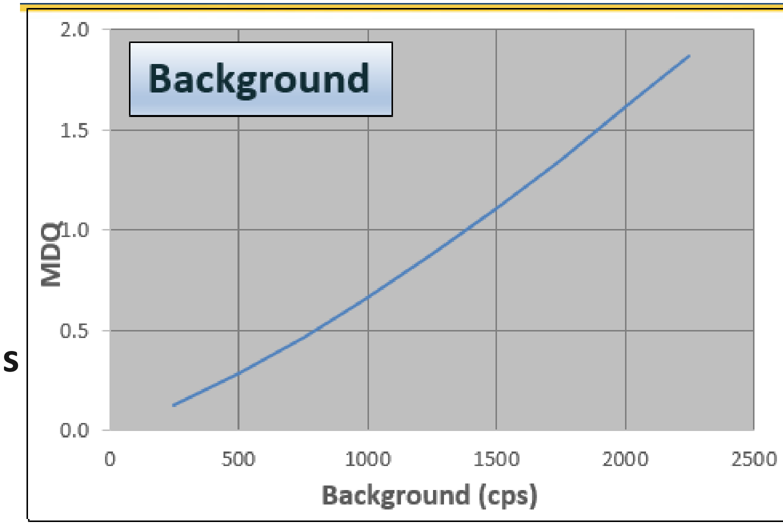
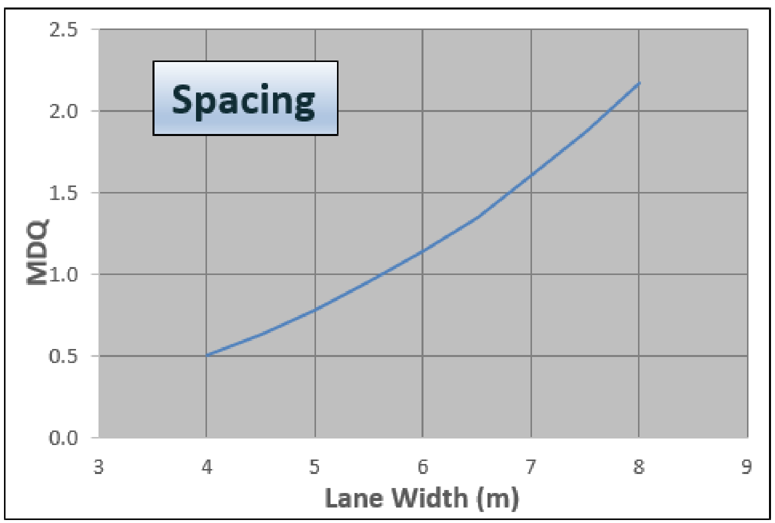
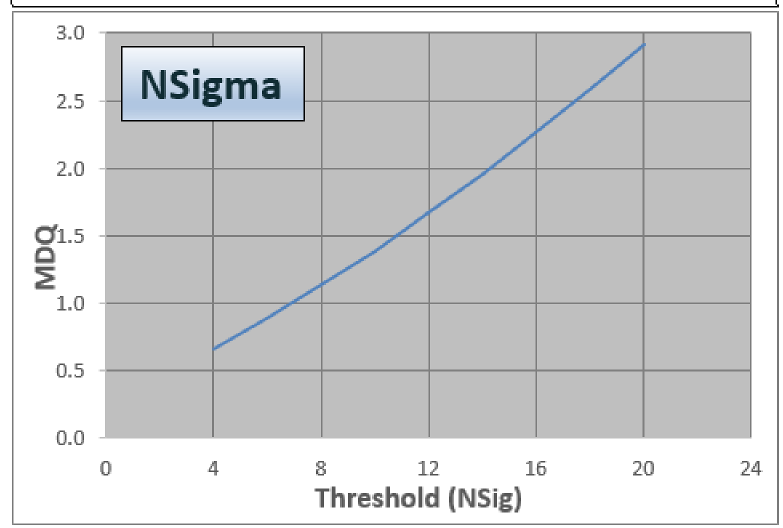
Lower is better

Parameter	Control Mechanisms
Background	repave, collimate
Speed	speed bumps, drop bar
Spacing	minimize at design phase
Alarm threshold (Nsigma)	country manager, customs
Background suppression	collimate, repave







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VII. RPM Parameters-Gamma

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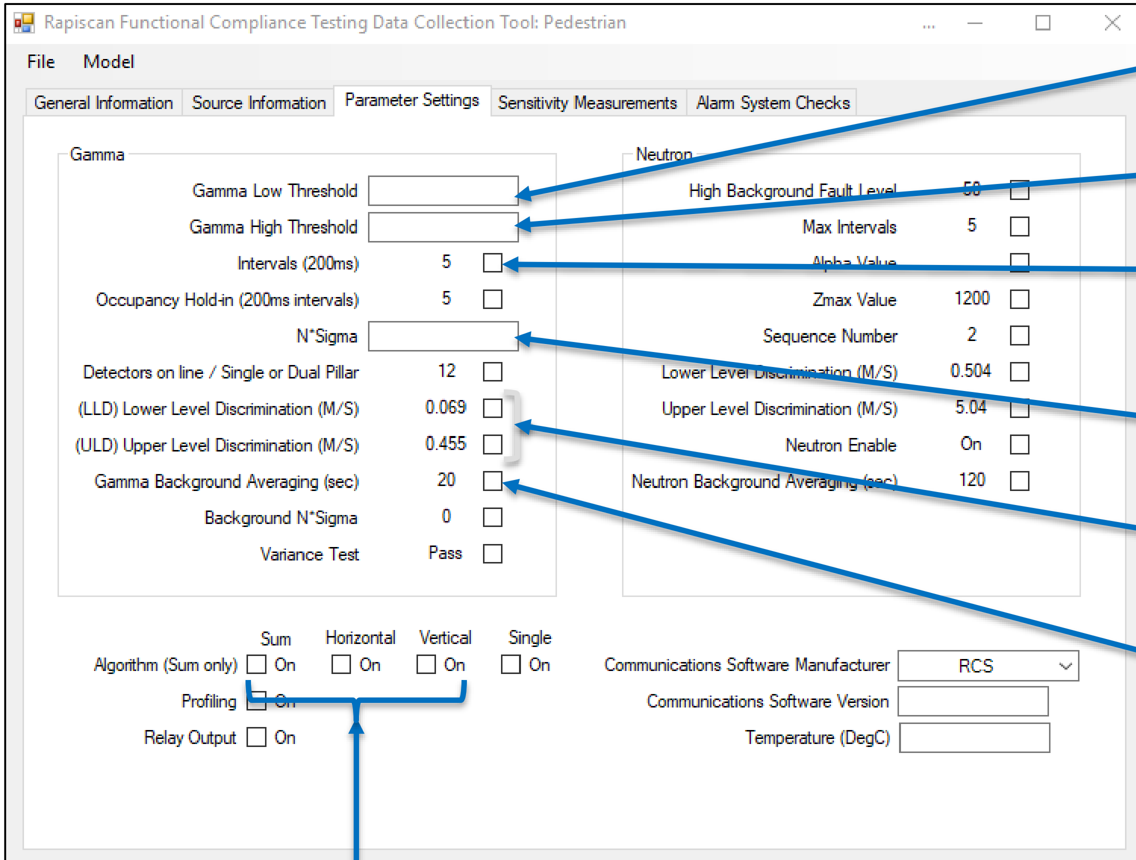

Detects malfunction: fault triggered on low count rate

Detects malfunction or creeping bkg: fault triggered on high count rate

Decision time: number of intervals

Detection threshold: number of sigmas above background

Voltage window for pulse height discrimination: about 20-180 keV

Detection threshold: number of sigmas above background

Alarm on various summed counts (1 decision each/200 ms)

Sum: ML+MU+SL+SU
Single: ML, MU, SL, and SU

Vert: ML+MU and SL+SU
Hor: ML+SL and MU+SU

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VII. RPM Parameters-Neutron

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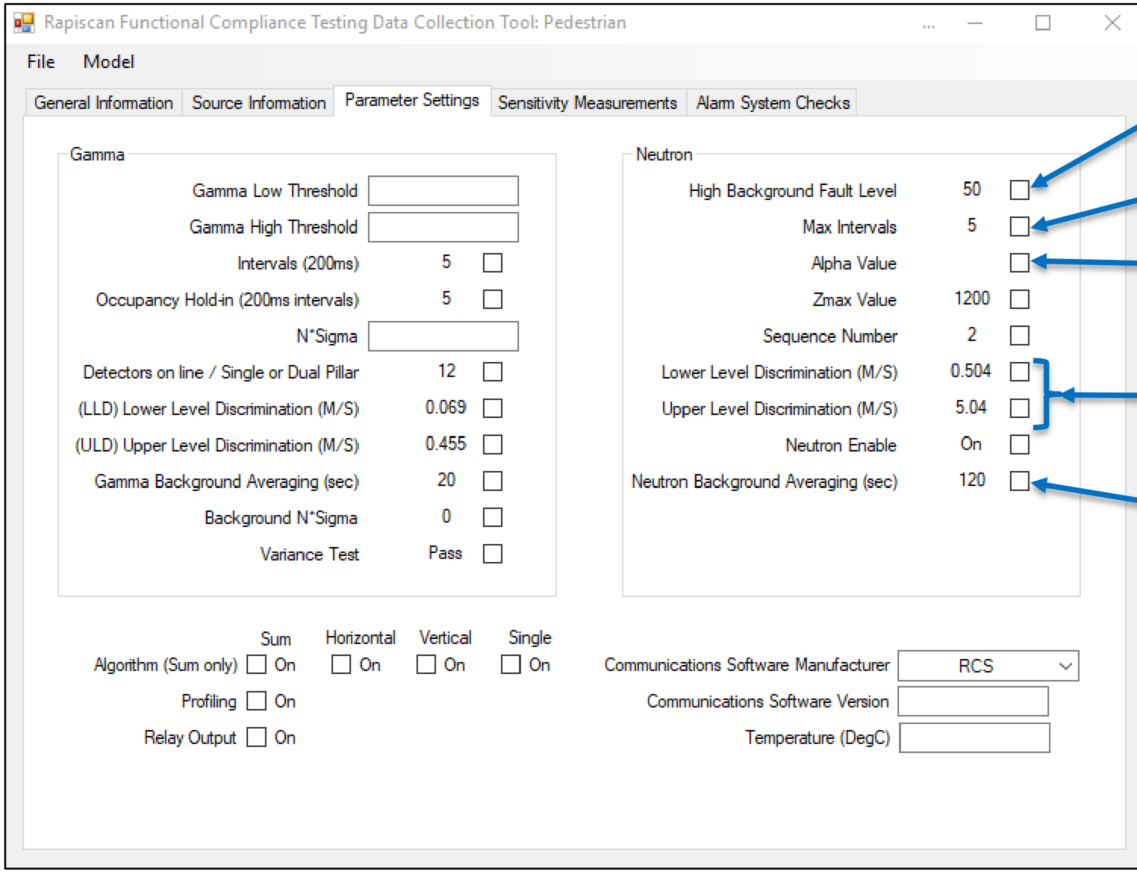

Detects malfunction or creeping bkg: fault triggered on high count rate

Decision time (max): number of intervals

Type I statistical error: false alarm rate (FAR) per million decisions.

Voltage window for pulse height discrimination

Background averaging time; important to have at 120 seconds to keep FAR low.

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Extras

Extra: Alarm Handling-Gamma[7]

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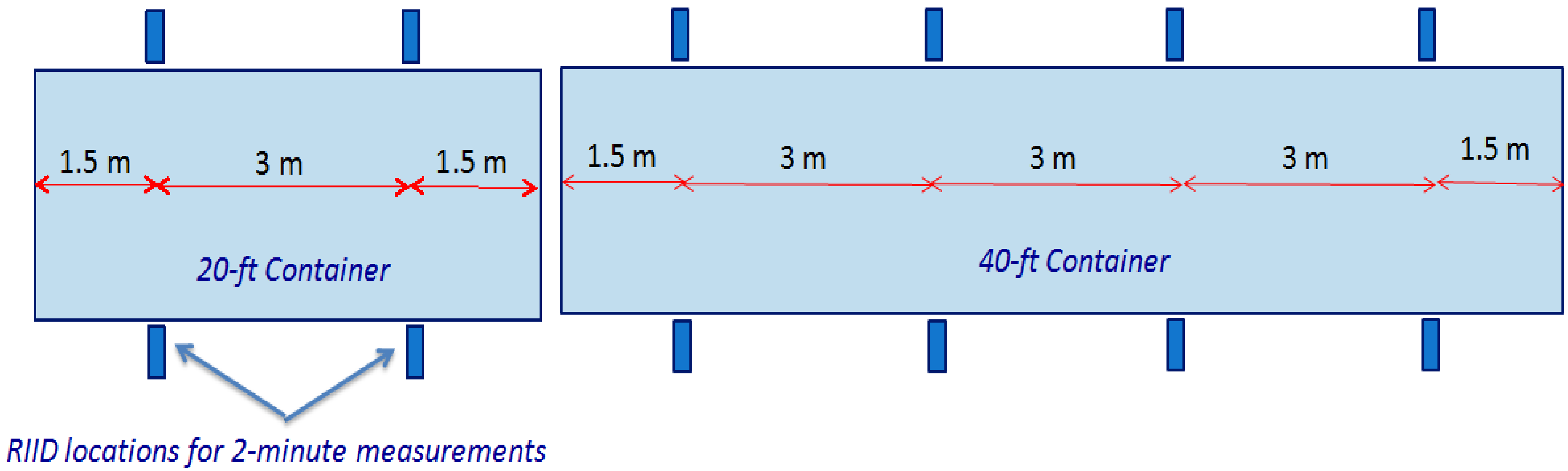
Recommended CONOPS for Containers or Large Trucks



Containers – use three-step process with RIIDs

1. Step scan with 120-s measurements at indicated locations, always use Detective or Micro-Detective when available
2. Search as trained – 20 cm/s, use any instrument but a pager; this search may find streaming paths
3. ID at any hotspots with Detective or Micro-Detective

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Extra: Gamma Spatial Response Function[3]

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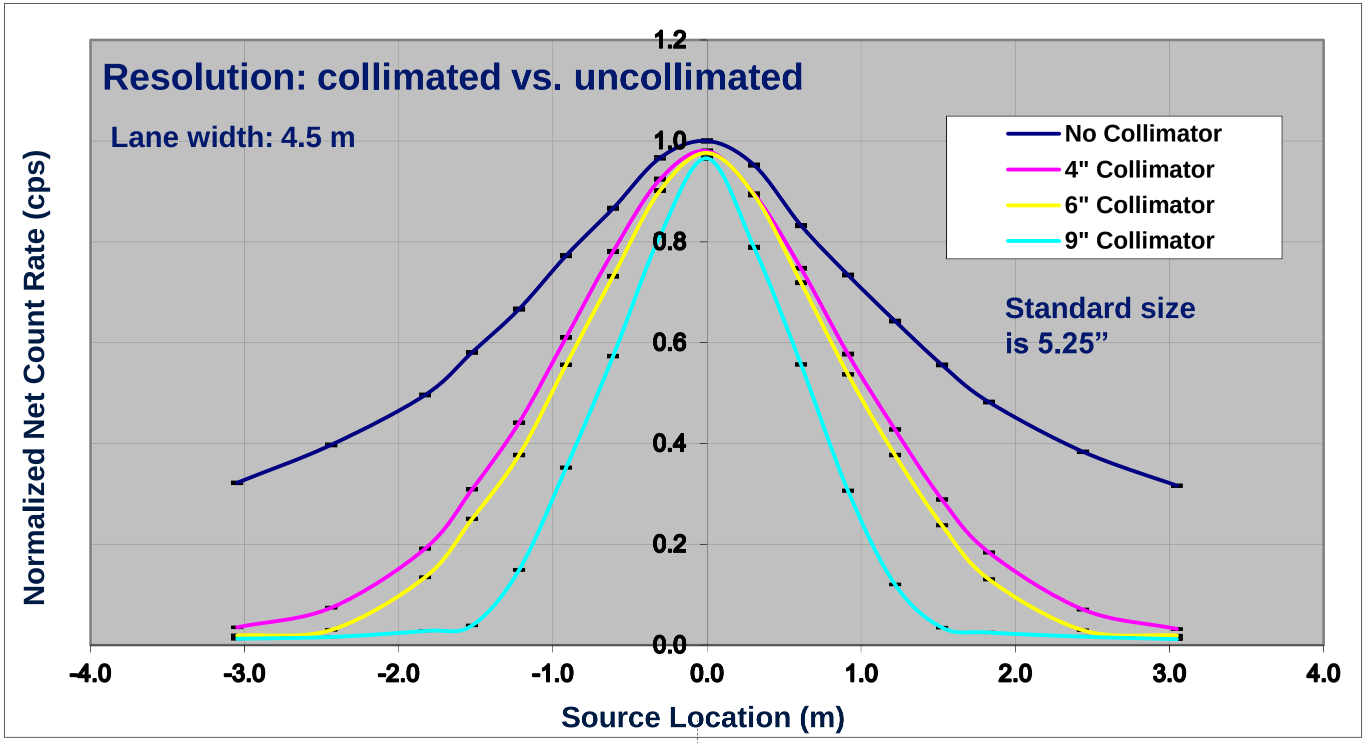

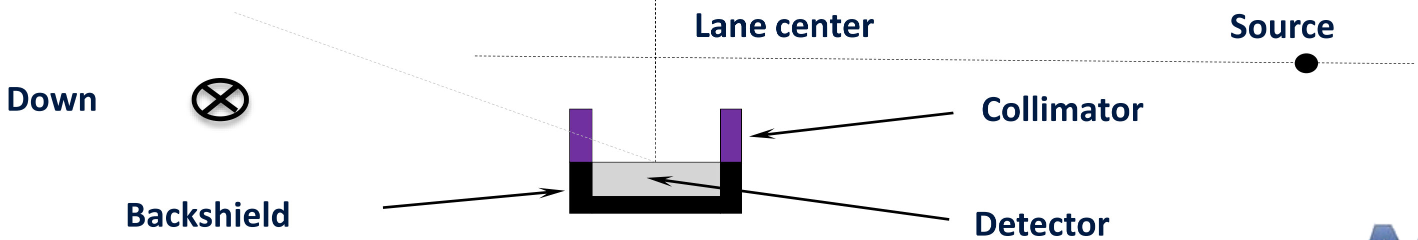

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Extra: NORM Activity Distribution in Commerce[6]

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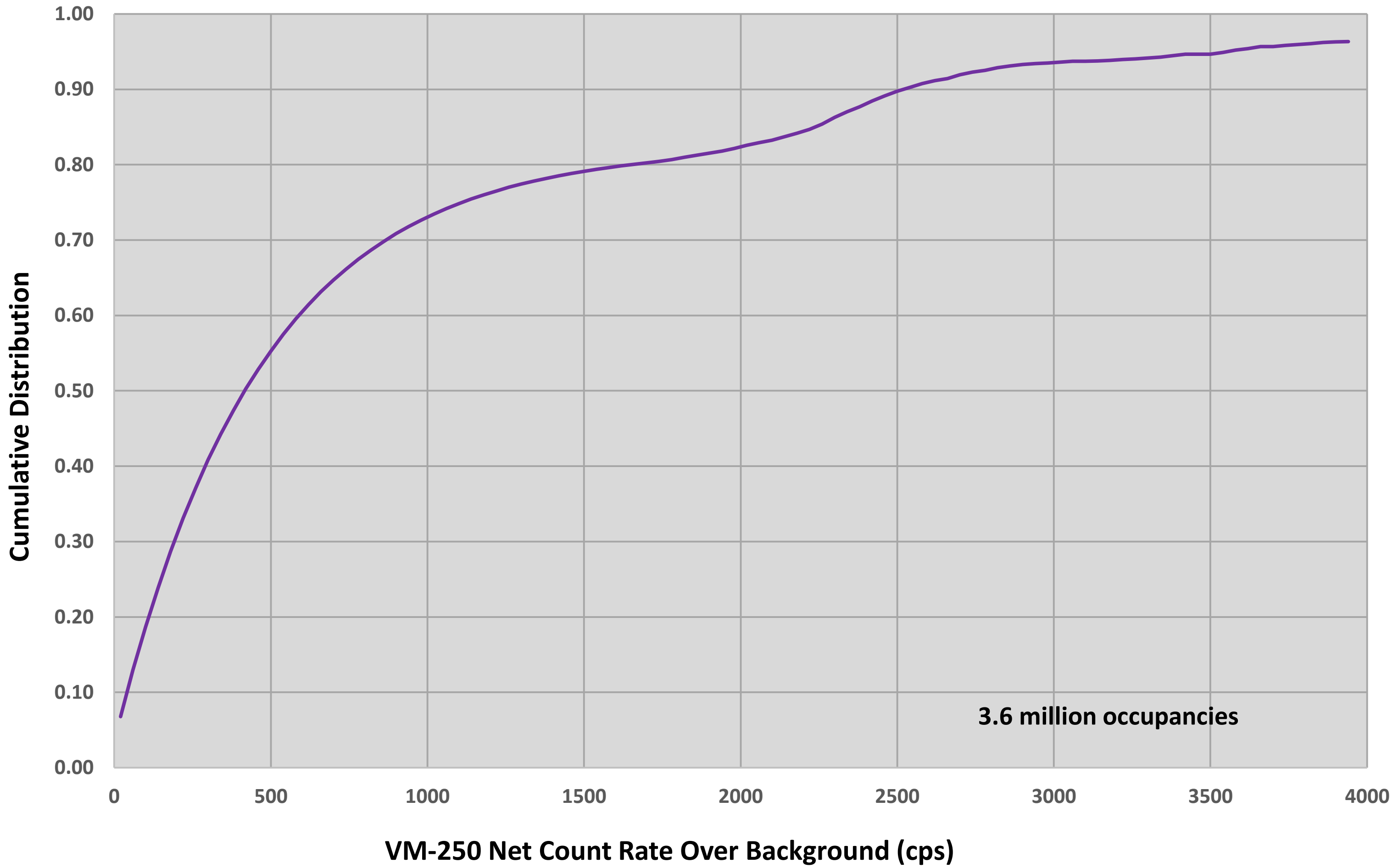

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Extra: Special Nuclear/Weapons Indicating Material[3]

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- **The term *special nuclear material* means plutonium, uranium enriched in the isotope 233 or 235, any other material the commission…(Atomic Energy Act of 1954)**
- **DU and normal uranium of any assay may be used in weapons (RDD7)**
- **DOE requires separated Np-237, Am-241, and Am-243 to be treated as SNM (DOE M471.4-6)**

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References

[1] US Senate Permanent Subcommittee on Investigations Hearing on Global Proliferation of Weapons of Mass Destruction, Senator Sam Nunn, October 31, 1995.

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[3] LA-UR-16-24400 Primary Inspection Analysis, John Rennie, July 2017.

[4] NSDD FY16 Q2 Quarterly review.

[5] LA-UR-16-24543 Primary Inspection Detectors, John Rennie, July 2017.

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[7] LA-UR-16-24419 Secondary Screening Process, Jim Toevs, July 2017